[0029] The preferred implementations of the present invention further make use of a dual, closed-loop power control method by which the central controller communicates with each of the mobile terminals within the coverage region, in accordance with a first closed control loop, and instructs each of the mobile terminals by transmitting commands thereto to increase or decrease its transmit EIRP as needed, based upon a receive signal-to-noise ratio ("Eb/No") of the monitored signal, to maintain communication link closure. With [[this]] <u>this</u> method, the ground station measures the Eb/No of the received RF signals and periodically sends commands back to the mobile terminals to increase or decrease the transmit power of each such mobile terminal to maintain the Eb/No within a desired control range.

[0032] In a preferred embodiment the present invention also makes use of a "reverse calculation" method for more accurately determining the PSD contribution of each mobile terminal. The "reverse calculation" method is a much more accurate method of determining aircraft PSD than "forward calculating" mobile terminal PSD by using an estimate of transmit EIRP made by the mobile terminal. In practice, it is both difficult and expensive for the mobile terminal to accurately estimate transmit EIRP. So the invention uses a novel method of "reverse calculating" mobile terminal EIRP by knowing the receive Eb/No at the ground station and working backwards through the link to determine the corresponding transmit EIRP of the mobile terminal. Once the transmit EIRP is determined, the PSD along the GEO plane and off of the GEO orbit plane can <u>be</u> determined in the manner described below.

[0048] Figures 11-13 are graphs of the PSD along the GEO arc of the RF signals transmitted by each of the three aircraft shown in Figure 10; [[and]]

[0049] Figure 14 is a graph illustrating how the aggregate PSD of the signals from the three aircraft shown Figure 10 remains below the regulatory PSD limit at all points along the GEO arc; [[and]]

[0058] The content center 24 is in communication with a variety of external data content providers and controls the transmission of video and data information received by it to the ground station 22. Preferably, the content center 24 is in contact with an Internet service provider (ISP) 30, a video content source 32 and a public switched telephone network (PSTN) 34. Optionally, the content center 24 can also communicate with one or more virtual private networks (VPNs) 36. The ISP 30 provides Internet access to each of the occupants of each aircraft 12. The video content source 32 provides live television programming, for example, Cable News Network ~~(C NN)~~ <u>(CNN®)</u> and ESPN<u>®</u>. The NOC 24 performs traditional network management, user authentication, accounting, customer service and billing tasks. The content center 24a associated with the ground station 22a in the second coverage region 14b would also preferably be in communication with an ISP 38, a video content provider 40, a PSTN 42, and optionally a VPN 44. An optional air telephone system 28 may also be included as an alternative to the satellite return link.

[0067] An advantage of the present invention is that the system 10 is also capable of receiving DBS transmissions of live television programming (e.g., news, sports, weather, entertainment, etc.). Examples of DBS service providers include DirecTV ~~an d Echostar .~~ <u>and Echostar.</u> DBS transmissions occur in a frequency band designated for broadcast satellite services (BSS) and are typically circularly polarized in North America. Therefore, a linear polarization converter may be optionally added to receive antenna 82 for receiving broadcast satellite services in North America. The FSS frequency band that

carries the data services and the BSS frequency band that carries DBS transmissions are adjacent to each other in the Ku-band. In one optional embodiment of the system 10, a single Ku-band receive antenna can be used to receive either DBS transmissions from DBS satellites 18c and 18f in the BSS band or data services in the FSS band from one of the FSS satellites 18a or 18b, or both simultaneously using the same receive antenna 82. Simultaneous reception from multiple satellites 18 is accomplished using a multi-beam receive antenna 82 or by using a single beam receive antenna 82 with satellites co-located in the same geostationary orbit slot.

[0083] Maintaining the aggregate EIRP spectral density below the known regulatory limit requires that each mobile system 20 sharing a return link satellite transponder (e.g., transponder $18a_1$) be under strict transmit power control. The system 10 employs a dual loop control system method whereby the ground segment 16 measures the receive "Eb/No" for each mobile system 20 accessing, or attempting to access, the system._ [[with]] With this method a first closed control loop is employed via the ground segment 16 to measure the receive Eb/No from each aircraft 12, and then to transmit EIRP control commands to the mobile system 20 to thereby maintain the Eb/No of the receive signal from the mobile system within a tight, predefined range. A second control loop implemented in the mobile system 20 on the aircraft 12 is used for maintaining the transmit EIRP at the level commanded by the ground segment 16, using [[said]] the first control loop, during rapid movement of the aircraft. The second control loop on the aircraft is often required for mobile transmit antennas, such as phased arrays, that experience changes in directivity (causing changes in EIRP) with scan angle. The preferred embodiment of the invention includes [[said]] the second control loop but the invention may

optionally be implemented without [[said]] the second control loop when using "constant aperture" transmit antennas, such as reflector and lens antennas, that do exhibit directivity changes with scan angle, or for mobile platforms that do not rapidly change attitude. The aircraft-to-ground control loop (i.e., the first control loop) has about 0.5 seconds of roundtrip GEO delay so it cannot react as quickly to aircraft movement.

[0084] The above-described dual control loop control method can maintain the receive signal Eb/No from each aircraft 12 within a tight control range of about +/-0.5dB with about 99.7% probability for the full range of typical aircraft motion. This power control system achieves two important objectives: maintaining the receive Eb/No for all aircraft 12 above a threshold Eb/No level corresponding to a desired bit error rate (i.e., 1E-9); and maintaining the time variation of Eb/No within a tight control range (i.e., +/-0.5 dB). The goal is for the mobile terminals to use the minimum transmit EIRP (and hence PSD) to close the communication link with a desired bit error rate (BER). The threshold Eb/No level for a 1E-9 BER is dependent on the forward error correction (FEC) code selected ~~(i.e., rate 1/3 ,rate , etc.)~~ and other waveform parameters. One preferred Eb/No control range used by the system 10 is illustrated in Figure 7. The performance of the control loop is determined by many design parameters, but key among them is the error in measuring receive Eb/No on the ground. The ground receiver (not shown) associated with the ground station 22 has typically fixed or slowly varying error in addition to a random (rapidly varying) error caused by the noise in the measurement value. In this example, the fixed error term requires that the control range be shifted up by 0.25 dB, as shown in Figure 7, so that the actual Eb/No stays above the threshold level.

[0086] Movement of the aircraft 12a causes the largest and fastest control loop disturbances. The aircraft's 12a transmit antenna 74 is always pointing its beam at the target satellite 18a so that changes in pitch and roll of the aircraft cause the elevation scan angle of the antenna 74 (or antenna 82) of its mobile system 20 to vary, as shown in Figure 8. A characteristic of a transmit phased array ~~antennas~~ antenna, if such is employed with the mobile system 20, is that the EIRP is proportional to $\cos^{1/2}\theta$, where θ is the elevation scan angle to the satellite 18a. Therefore aircraft pitch/roll disturbances can cause a change in antenna elevation scan angle, which can cause a change in antenna directivity, leading to a change in EIRP. Changes in the EIRP lead to proportional changes in receive Eb/No on the ground, which is measured by the receiver at the ground station 22. The power control system then sends a command back to the aircraft to adjust EIRP, either up or down. In practice, the control loop managed by the mobile system 20 on each aircraft 12 minimizes the EIRP variations caused by aircraft disturbances, [[By]] by measuring the change in antenna elevation scan angle and adjusting the drive level into the antenna (and hence the transmit power) to compensate for the change in directivity of the antenna, thereby maintaining the EIRP at the last commanded level.

[0087] The NOC 26, as mentioned above, is also used to determine the PSD contribution of each mobile system 20 accessing (or attempting to access) the system 10. Determining the PSD of each mobile system 20 is accomplished using a "reverse calculation" method. The first step in determining aircraft PSD is to determine the EIRP of the signal of the transmitter subsystem 64 on the aircraft 12a. Rather than have each aircraft 12 directly report their EIRP to the NOC 26, the system 10 uses a much more accurate method to work backwards from a known receive Eb/No at the ground station 22

through the target satellite 18, to determine the transmit EIRP of the signal from the mobile system 20. In [[the]] a preferred embodiment of the invention the performance of the return link is completely driven by the link between the aircraft 12a and the target satellite 18a. Under this condition the receive Eb/No at the ground station 22 is known to be identical to the Eb/No at the output of the satellite transponder. ~~Using first principles, the~~ The following equation for aircraft EIRP projected towards the target satellite 18a as a function of receive Eb/No at the ground station 22 is ~~easily derived via~~ represented by equation 1 below:

[0091] R = return link data rate[[.]]

[0093] [[K]] k = Boltzmann's constant

[0102] The geometry between the mobile terminal 20 and the target satellite 18 must be accurately [[know]] known to solve equations (1) and (2). Therefore, the invention includes a method whereby all mobile terminals 20, periodically report their location and attitude to the NOC 26 using the return link.

[0115] Because the PSD contribution from each mobile system 20 is dependent on its location (and scan angle in the case of PAA antennas), and the location of the aircraft 12 will change over time, the PSD contribution from each mobile system 20 will be time varying. Accordingly, the system 10 requires that each mobile system 20 periodically report its position and antenna pointing angle to the central controller 26a so that the PSD contribution of each mobile system 20 to the aggregate can be updated. However, the PSD of the RF signal from any given mobile system 20 is expected to change slowly with time, even for relatively fast moving mobile platforms such as commercial jet aircraft. Accordingly, the central controller 26a typically will not

need to calculate mobile system PSD patterns more often than once every several minutes. The exception to this statement occurs for mobile antenna that have gain patterns that are very sensitive to scan angle (such as phased array antennas). Mobile systems 20 having these antennas must report their parameters (position and antenna scan angle) more often when [[the]] its associated aircraft ~~or mobile system 20~~ is rapidly changing it's heading or attitude.

[0151] Block 182 represents a "limited discrete time integrator" which is contained in the software on the ground. Block 182 produces the time integral of its input on its output. The integration is done in discrete time fashion using the ~~so-called~~ so-called "Forward Euler" method. The sample period of this integrator is one second. The integrator is limited (so-called "anti-windup") in that it stops integrating when the output goes above a given value (or below the negative of that value). It will start integrating again when the input reverses its sign, thereby reducing the output from its limited value.